# 8.2 Climate

## 8.2.1 Introduction

This section discusses local climate characteristics, seasonal conditions and potential extreme climatic events including cyclones, flooding, drought and bushfires within the LNG facility study area. Non climatic associated hazards and risks are described in Section 10.

## 8.2.2 Existing Environmental Values

The climate of the LNG facility study area comprises a sub-tropical coastal climate, characterised by increased rainfall and hot humid conditions in the summer months (November to March). This section details the climate for the study area utilising meteorological data collected at the Gladstone Post Office (1872 to 1958) and Gladstone Radar (1957 to 2008) operated by the Bureau of Meteorology (BOM). These sites are located in close proximity to the LNG facility study area and are indicative of the local climatic conditions.

### 8.2.2.1 Temperature

The mean daily maximum and minimum temperatures at Gladstone Radar are presented in Figure 8.2.1. On average, the daily temperature in summer ranges from 22.5 °C to 31.2 °C, and in winter ranges from 13.3 C to 22.8 °C. The highest temperature recorded at the Gladstone Radar site was 42.0 °C. The region has a mean number of 4.5 days per year when the temperature exceeds 35 °C. The lowest recorded temperature was 4.4 °C.

### 8.2.2.2 Rainfall and Evaporation

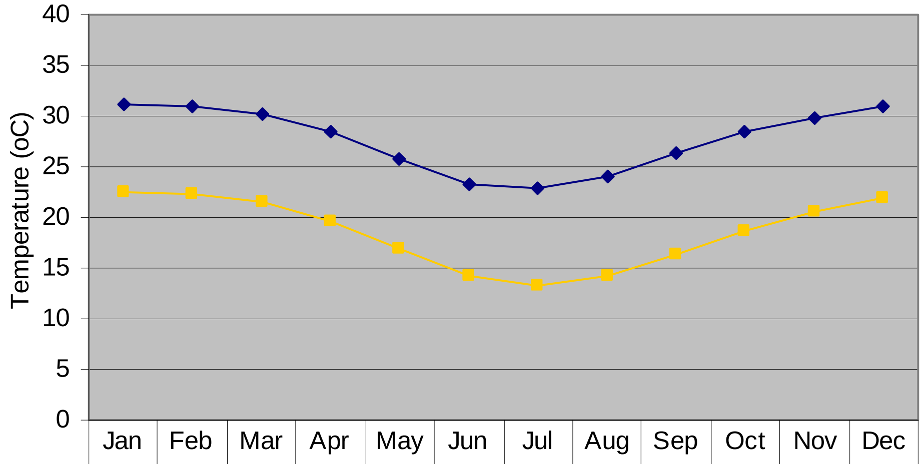
The Gladstone Radar site experiences an average annual rainfall of 878 mm, with an average of 97.6 rain days per year. The highest monthly rainfall (709.8 mm) and highest daily rainfall (248.0 mm) events were both recorded in February 2003.

The mean monthly rainfall is presented in Figure 8.2.2. Rainfall generally occurs during the summer months (November to March), with monthly rainfall figures ranging from 76 mm to 144 mm per month. Rainfall during these months typically represents two-thirds of the annual total rainfall. Typically, little rainfall is recorded in the months of May to September (less than 60 mm per month).

The mean daily pan evaporation rate for Gladstone Radar is presented in Figure 8.2.3. Evaporation rates are highest from November through to February, with a mean daily potential evaporation rate of between 5.9 mm/day and 6.3 mm/day (approximately 177 mm/day to 189 mm per month). The winter months record a daily evaporation rate of approximately 3 mm (approximately 90 mm per month).

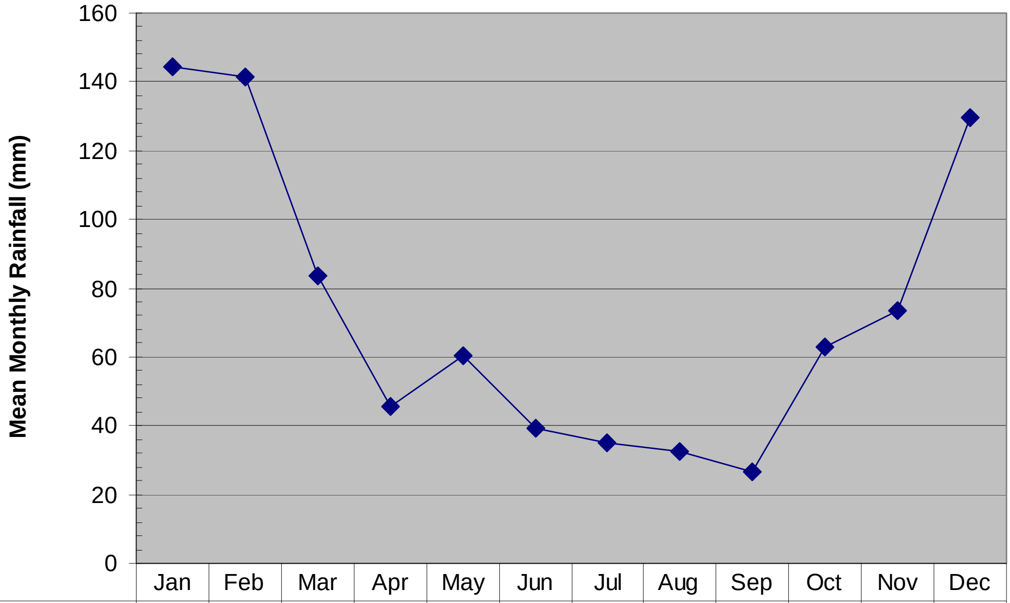
### 8.2.2.3 Relative Humidity

The 9 am and 3 pm relative humidity levels recorded at the Gladstone Radar site are presented in Figure 8.2.4. The relative humidity measured at 9 am ranges (on monthly averages) from 64 % (spring) to 72 % (summer). Records of the monthly average relative humidity indicate that at 3 pm the lowest value is 53 % in winter and the highest value is 64 % in summer.



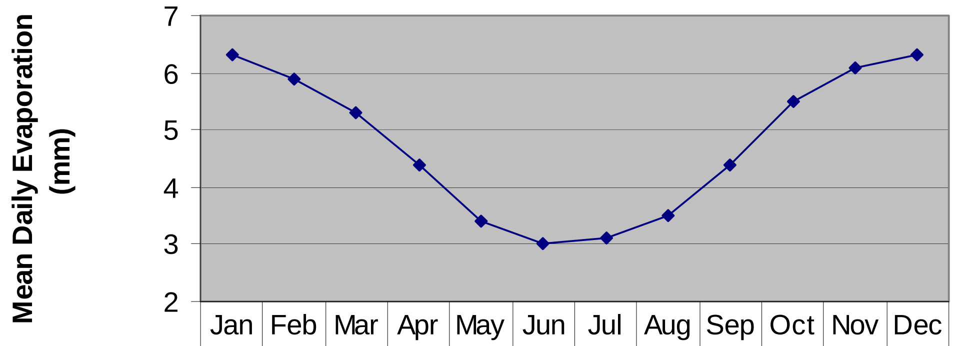

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean daily maximum temperature (°C) | 31.2 | 30.9 | 30.2 | 28.4 | 25.7 | 23.2 | 22.8 | 24.0 | 26.4 | 28.4 | 29.9 | 31.0 |
| Mean daily minimum temperature (°C) | 22.5 | 22.4 | 21.5 | 19.6 | 17.0 | 14.3 | 13.3 | 14.2 | 16.4 | 18.7 | 20.5 | 21.9 |

**Figure 8.2.1 Mean Daily Maximum And Minimum Temperature At The Gladstone Radar Site**



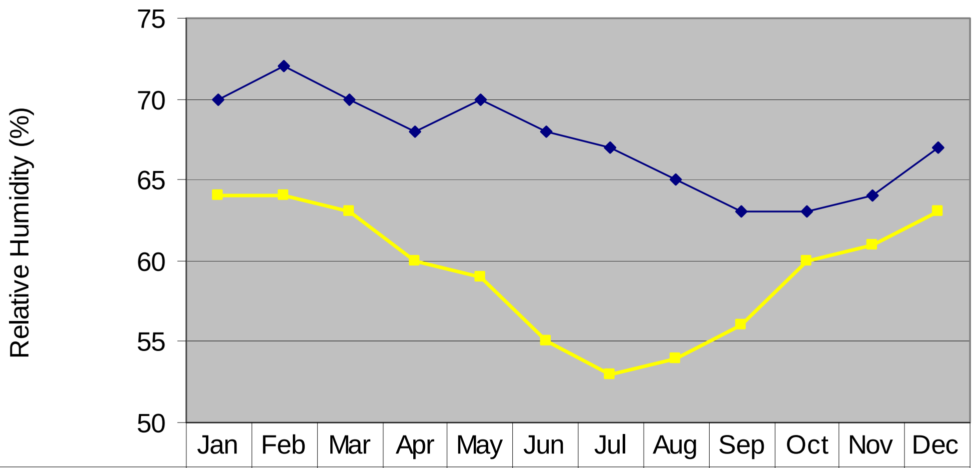

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean monthly rainfall (mm) | 144.2 | 141.5 | 83.5 | 45.5 | 60.5 | 39.4 | 35.2 | 32.4 | 26.6 | 62.9 | 73.6 | 129.8 |

**Figure 8.2.2 Mean Monthly Rainfall at the Gladstone Radar Site**




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean daily evaporation (mm) | 6.3 | 5.9 | 5.3 | 4.4 | 3.4 | 3.0 | 3.1 | 3.5 | 4.4 | 5.5 | 6.1 | 6.3 |

**Figure 8.2.3 Mean Daily Pan Evaporation (mm) at the Gladstone Radar Site**




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean 9am relative humidity (%) | 70 | 72 | 70 | 68 | 70 | 68 | 67 | 65 | 63 | 63 | 64 | 67 |
| Mean 3pm relative humidity (%) | 64 | 64 | 63 | 60 | 59 | 55 | 53 | 54 | 56 | 60 | 61 | 63 |

**Figure 8.2.4 Mean 9 am and 3 pm Relative Humidity (%) at the Gladstone Radar Site**

### 8.2.2.4 Wind

Wind data for the Gladstone area is available from the BOM and Environmental Protection Agency (EPA) monitoring sites. Data for the year 2001 has been incorporated into the Gladstone Airshed Modelling System (GAMS), a regional dispersion modelling tool that is available from the Queensland EPA. GAMS is described in more detail in Section 8.8.

Wind data for 2001 have been extracted from GAMS for the proposed LNG facility study area location, based on a 10 m measurement height. The modelled average wind speed for year 2001 is 3.7 m/s, which is a higher wind speed than recorded at Gladstone. A wind rose has been prepared from these data, and is presented in Figure 8.2.5. The dominant wind direction at the site is from the east through to the south, with wind speeds reaching up to 12 m/s. In general, stronger winds originate from the east and eastsoutheast, with weaker winds from the south and south-southeast. Daily and seasonal wind trends are detailed in Appendix S.

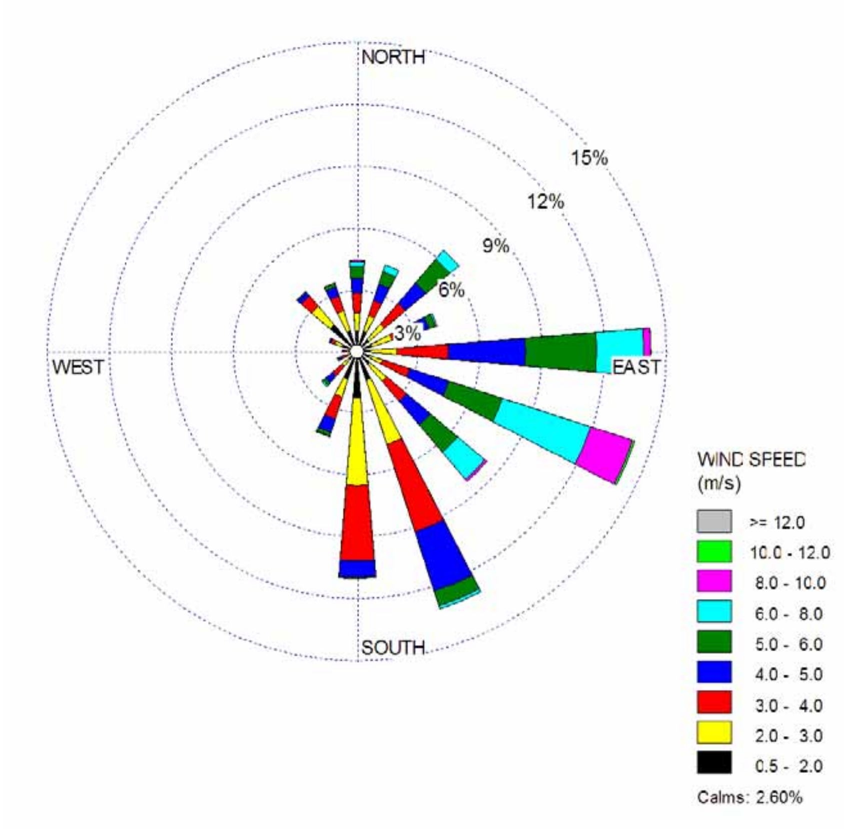



**Figure 8.2.5 Wind Rose for the LNG Facility Study Area (2001), Derived from GAMS Modelling Data**

### 8.2.2.5 Atmospheric Stability

Atmospheric stability is a parameter that is derived from wind data and temperature profiles at the site. These data are used to characterise the conditions that lead to enhanced (unstable conditions) or poor atmospheric dispersion (stable conditions).

The frequency of occurrence of the atmospheric stability classes, based on data derived from GAMS for 2001, is presented in Table 8.2.1. This shows that the site is heavily influenced by neutral atmospheric conditions (33 %), with only approximately 7 % of conditions being classified as Extremely Unstable or Unstable.

### Table 8.2.1 Frequency of Atmospheric Stability Classes at the Project Site

| Atmospheric Stability Class | Frequency of Occurrence | Description of Category |
|---|---|---|
| A | 0.3 % | Extremely Unstable |
| B | 6.9 % | Unstable |
| C | 16.8 % | Slightly Unstable |
| D | 32.8 % | Neutral |
| E | 14.4 % | Slightly Stable |
| F | 29.1 % | Stable |

## 8.2.2.6 Mixing Height

Hourly mixing height data at the LNG facility study area have been derived from GAMS for 2001, and is presented in Figure 8.2.6 as box-and-whisker plots. At night, the mixing height is very low and close to the lower limit of 50 m used in the model. The mixing height rises sharply after sunrise, and peaks at around 1,200 m to 2,000 m in the afternoon for the majority of the day (10 to 90th percentile). Daily maximum mixing height is lower in the winter than the summer due to less solar heating effects.

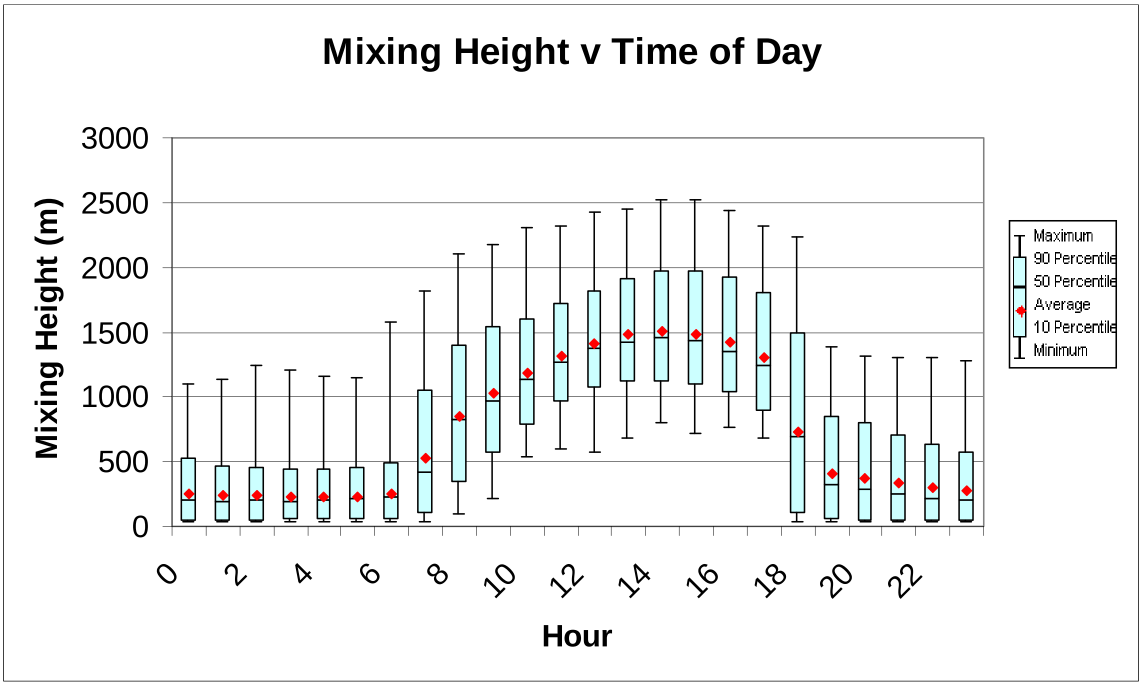



Figure 8.2.6 Mixing height by time of day for the LNG Facility study area

## 8.2.2.7 Temperature Inversions

Air temperature generally decreases with altitude, with buoyancy causing the air to mix vertically. This is typical of sunny daytime conditions which are described as unstable. Temperature inversions occur when the temperature increases with height, which may only occur in a shallow band of air. This has the effect of trapping colder parcels of air below the warmer air above. Any pollution source that is emitted below this trapped inversion layer will have limited vertical mixing, and thus the pollutant will remain trapped and will have limited opportunity for dilution with fresh air. This effect also applies to ground-level noise sources. Inversions commonly develop at night, when the surface cools due to radiation heat loss to the atmosphere.

Temperature inversions often create the worst-case meteorological conditions for air dispersion and noise transmission, and thus are critical conditions for adverse impacts at nearby locations. The EPA's *Planning for Noise Control* guideline notes that temperature inversions can create significant noise impacts that warrant further assessment if they occur more than 30 % of the time under the following conditions:

- Winter (June, July and August);
- Night-time period (1800 hours to 0700 hours);
- Temperature inversion strength of at least 3°C per 100 m plus a source-to-receiver drainage flow wind speed of 2 m/s; and
- Moderate (F-class stability) inversions.

The frequency of temperature inversions at Curtis Island has been determined from the Calmet modelled meteorological data for 2001 (Appendix S). These data were extracted from all the vertical levels in the model (between 10 m and 2,750 m elevation above ground level) for June, July and August. An inversion lasting at least one hour (the time-step that is used in Calmet) was found to occur for approximately 2 % of hours in the year, or 141 separate inversion events over 30 days in winter. This equates to 18 % of the hours in June, July and August, representing the conditions under which adverse air quality and noise impacts are most likely to cause nuisance.

### 8.2.2.8 Extremes of Climate

Extremes of climate include droughts, floods, storm and tide surge and cyclones. The LNG facility study area has the potential to be influenced by flood conditions due to proximity to the Calliope River, as well as experience cyclones and storm surge. Each of these potential extremes of climate and their relevance to the study area is described below.

#### *Drought*

Drought affected areas are declared by the Commonwealth Department of Agriculture, Fisheries and Forestry (DAFF) as areas of “Exceptional Circumstances” (EC). EC comprise weather conditions based on historical records that are rare, severe and prolonged occurring only once in every 20 - 25 years (DAFF, 2009) which includes exceptionally high temperatures, low rainfall and low soil moisture (Hennessey et al., 2008).

No EC declarations are in force for Curtis Island. The extent of drought declared land within the entire GLNG Project study area is shown in Figure 7.2.7.

#### *Floods*

The proposed LNG facility is to be located on Curtis Island, within the Boyne – Calliope sub-region of the Fitzroy Basin.

Within the designed LNG facility study area all drainage features are ephemeral in nature having small catchments less than 5 $km^2$ in size. The proposed process area and perimeter road are predicted to be prone to flooding after short, intense rainfall events. A flood assessment, undertaken as part of this study, predicted that the perimeter road would be flooded to depths of 0.5 – 1 m, in events of a 10 yr ARI magnitude.

#### *Cyclones*

Tropical cyclones threaten the Gladstone area mostly in January, February and March, although some cyclones have occurred in April (URS, 2006). There is a strong year-to-year variation in the number of tropical cyclones in the region, with nearly twice as many impacts occurring during La Niña conditions than during El Niño. Tropical cyclones are accompanied by destructive winds and heavy rain which often produces disastrous flooding overland after the cyclone crosses the coast (landfall). Over the ocean, the intense wind fields generate very large waves and strong ocean currents, which can result in coastal inundation at landfall (Callaghan, 2003). On average, approximately 1.4 cyclones pass within 500 km of Gladstone each year. In the past 101 years of BOM records, 13 cyclones have passed within 100 km of Gladstone between 1913 and 1992 (BOM, 2007). A summary of cyclones that have impacted Gladstone are provided in Table 8.2.2, with information sourced from Bath and Deguara (2002).

**Table 8.2.2 Summary of Significant Cyclone Information for Gladstone**

| Year | Impact |
|---|---|
| 1864 | Wind and rain damage within Gladstone |
| 1949 | Tropical cyclone hit Gladstone with widespread damage. Approximately 1500 homes damaged.<br>Heavy seas closed Gladstone port with land flooding |
| 1950 | Tropical cyclone over Gladstone/Hervey Bay. Sea water flooding at Hervey Bay. Floods SE Qld. including northeastern suburbs of Brisbane. |
| 1971 | Tropical cyclone near Rockhampton. Crops lost near Gladstone. Storm surge 0.6m-0.9m observed. |
| 1972 | Tropical cyclone south east of Gladstone. Wind damage. Huge seas. |

### *Elevated Water Levels*

Water levels along the coastline during cyclone events can be substantially higher than normal due to storm surge effects. The storm tide level is the result of tide plus surge, which may peak at any stage of the tidal cycle. Hence, abnormally high storm tide levels may result from extreme surge peaks coinciding with moderate to high tides, or moderate surges coinciding with high tides. The probability of an extreme surge peak coinciding with a spring high tide is low.

#### Storm Surge

A storm surge is an increase in local sea level to a height markedly above the predicted tide level, and is usually caused by a combination of low barometric pressure and cyclonic wind fields. High sea levels can occur when storm surge events coincide with a high tide. Under these conditions, storm surges can cause widespread flooding of adjacent low-lying coastal areas.

Between 1949 and 1992, there have been at least eight separate storm surge events that have occurred at Gladstone. Of these, about a quarter resulted in storm tide levels reaching above the Highest Astronomical Tide (HAT) level (URS, 2007). Storm tide levels at Australian Height Datum (AHD) modelled by James Cook University (2004) are summarised in Table 8.2.3 for various recurrence intervals excluding wave-set up and climate change effects.

**Table 8.2.3 Peak Storm Tide Levels (Present Day 2003)**

| Location | Storm Tide Level (m AHD*) | | |
|---|---|---|---|
| | 100 year ARI | 500 year ARI | 1000 year ARI |
| Gladstone | 2.82 | 3.51 | 3.80 |
| Tannum Sands | 2.50 | 3.05 | 3.31 |

*Australian Height Datum

Potential flooding issues are considered to be associated with storm surges and tidal inundation. The region's key tidal data for Port Curtis are presented in Table 8.2.4.

### Table 8.2.4 Tide Levels at Gladstone (Standard Port)

| Tidal Plane | Tide Levels (m AHD) |
|---|---|
| Highest Astronomical Tide (HAT) | 2.42 |
| Lowest Astronomical Tide (LAT) | -2.27 |
| Mean High Water Spring (MHWS) | 1.64 |
| Mean Low Water Spring (MLWS) | -1.60 |
| Mean High Water Neap (MHWN) | 0.79 |
| Mean Low Water Neap (MLWN) | -0.75 |

It can be seen that there is some amplification (increase) in the predicted storm tide level moving into Port Curtis from the south. There is a possibility that slightly greater amplification and hence storm tide levels would occur at the proposed LNG facility site on Curtis Island than have been reported for Gladstone in Table 8.2.3 (WBM, 2008).

#### Climate Change

With respect to climate change, there is significant scientific opinion that baseline changes to climate may occur within the design life of coastal and ocean community infrastructure. However, despite the growing body of scientific literature and knowledge, there are still no definitive predictions of its effects or potential impacts (WBM, 2008).

The climate models predict that there will be a regional variation in future sea level rise, predominantly due to spatial variations in the contribution made by ocean thermal expansion. Predictions reported by CSIRO (2007) indicate that future sea level rise along the eastern Australian coastline may be up to 12 cm greater than the global average by 2100 (WBM, 2008).

In summary, the total mean sea level rise along the eastern Australian coastline is estimated to be in the range 28 - 91 cm by the year 2100. This will occur gradually at first as we continue to accelerate from the historic rate of 1.7 mm per year and then more rapidly as the year 2100 is approached.

The Queensland Government Ocean Hazards Assessment Study examined the potential implications for storm tide statistics based on three GHG scenarios:

a) Combined effect of an increase in Maximum Potential Intensity (MPI) of 10 % and a poleward shift in tracks of 1.3°.

b) Increase in frequency of tropical cyclones of 10 %.

c) Mean sea level rise of 0.3 m.

The mean sea level rise component (c) has an almost linear effect on the resultant storm tide levels, while the 10 % increase in cyclone frequency (b) has negligible impact. The combined increase in intensity and poleward shift in tracks (a) becomes increasingly significant with large return periods.

The resultant storm tide levels predicted with the combined greenhouse scenarios for the 50 year and 100 year period are presented in Tables 8.2.5 and 8.2.6 respectively.

### Table 8.2.5 Peak Storm Tide Levels (Combined Greenhouse Scenarios 50 year Planning Period)

| Location | Storm Tide Level (m AHD) | | |
|---|---|---|---|
| | 100 year ARI | 500 year ARI | 1000 year ARI |
| Gladstone | 3.33 | 4.18 | 4.51 |
| Tannum Sands | 2.95 | 3.64 | 3.94 |

Source: Queensland Government (2004)

### Table 8.2.6 Peak Storm Tide Levels (Combined Greenhouse Scenarios 100 year Planning Period)

| Location | Storm Tide Level (m AHD) | | |
|---|---|---|---|
| | 100 year ARI | 500 year ARI | 1000 year ARI |
| Gladstone | 3.58/3.94* | 4.43/4.79 | 4.76/5.12 |
| Tannum Sands | 3.20/3.56 | 3.89/4.25 | 4.19/4.55 |

*Mid-range/High-range sea level rise by 2100.

## *Extreme Wave Conditions*

Wave conditions associated with the penetration of long-period swell and the generation of local wind-waves by cyclonic winds have the potential to affect coastal areas. The penetration of long-period swell was modelled in Connell Wagner (2007) identifying that these ocean swells are generally blocked by Facing Island and the southern boundary of the harbour westwards from South Trees Inlet. Swell does not propagate far enough into the Port of Gladstone to have a significant impact on the location of the proposed LNG facility.

Local wind wave modelling from the same study (Connell Wagner, 2007) identified that locally generated wind waves have the potential to be larger at the location of the proposed LNG facility than ocean swell waves penetrating to the site. Local wind waves were modelled for a cyclonic 50 m/s wind speed and a variety of wind directions, with a water level of 3.4 m AHD approximately corresponding to a 100 year average recurrence interval (ARI) storm tide. No assessment was made of the annual exceedance probability of these combinations of wind speed, direction and water level.

Significant wave heights at the proposed LNG facility site were found to be greatest for winds blowing from the westerly quadrant due to the relatively unconstricted fetch in this direction. In the channel immediately offshore of the proposed LNG facility site the channel depth is approximately –12 m AHD. The 50 m/s wind generated significant wave heights ($H_s$) between 2.5 - 3.0 m, depending on direction. In general, the spectral peak period ($T_p$) of incident waves generated by such a cyclonic wind would be around 5 s.

## *Bushfires*

The climate factors which exert most influence over conditions conducive to the generation of bushfires are temperature, winds and humidity (BOM, 2009). A combination of high temperature, high winds, and low humidity increases fire danger, particularly in spring.

The LNG facility site is within the Gladstone Regional Council Local Government Area (LGA). The Rural Fire Service and Queensland Fire and Rescue Service (RFS, 2009) modelled the bushfire risk of the Gladstone LGA based on factors of slope, aspect and vegetation. Bushfire risk for the entire Curtis Island is identified as being predominantly medium, as shown in Figure 7.2.10.

Bushfire management strategies include the provision of water supply (recycled) for fire fighting especially near the LNG facility and other project buildings, as well as creating an asset protection zone of at least 20 m to minimise fuel load.

### 8.2.3 Potential Impacts and Mitigation Measures

The climatic conditions of the study area are prone to periodic high intensity rainfall events associated with cyclones and other storm events. Erosion potential and management strategies to minimise sediment loss from disturbed areas along and adjacent to the LNG facility are addressed in Section 8.3 and in Appendix L3.

Natural hazards are not considered a major risk for the study area. However, both flood and cyclone associated storm surge may become an issue at some point during the expected life of the LNG facility, with possible closure of the port. However, the designed ground level for the LNG facility is 13 m AHD for protection from the elements. The plant will also be designed to withstand climatic conditions for the area and will be able to operate even in the event of the port closing due to weather.

An emergency management plan will be developed to address all foreseeable site specific risks such as fire and flooding, as part of the Santos Environment, Health and Safety Management System (EHSMS). It will include appropriate contact details of all relevant emergency services. The risk of natural hazards is considered as part of the business risk management process, with appropriate controls and monitoring requirements set out in the emergency management plan being a fundamental part of the risk management plan (refer to Section 10).